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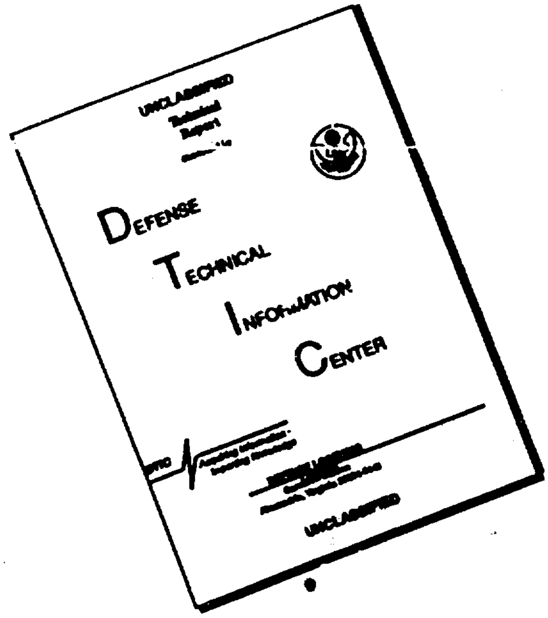

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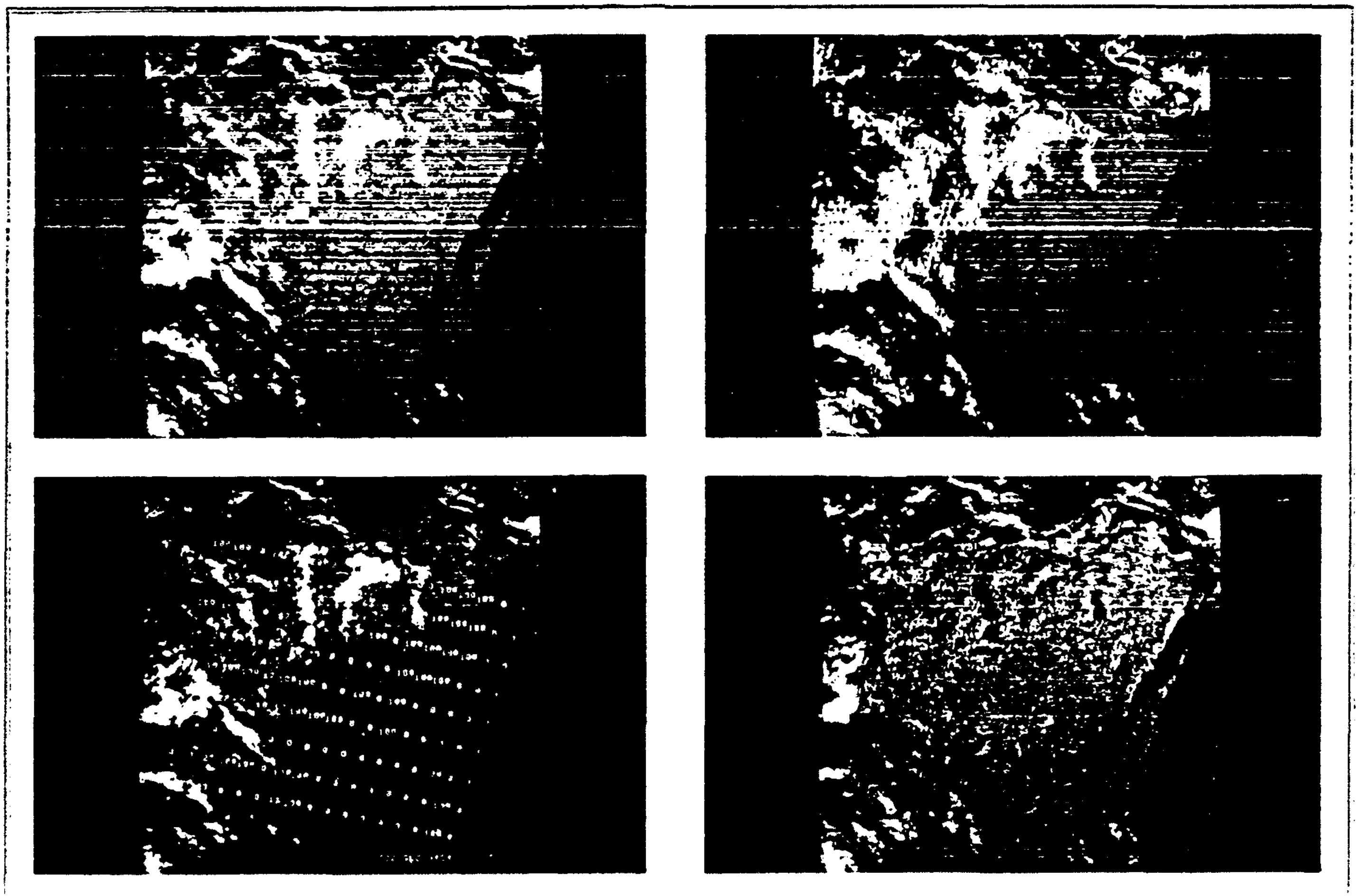

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9B.5

THE ASSIGNMENT OF WIND DIRECTION FOR OPERATIONAL ASSIMILATION OF SSM/I WIND SPEED DATA

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1. INTRODUCTION

Providing environmental support for Navy operations requires special attention to the marine boundary layer. Accurate meteorological nowcasts and forecasts play a key role in weapons system support, aircraft operations, and optimum-track ship routing. Furthermore, surface wind stresses and heat fluxes from the atmospheric model are used to drive ocean thermodynamic and hydrodynamic models (Clancy, 1987). Through these coupled air/ocean systems, the atmosphere indirectly plays a role in search and rescue missions and submarine operations.

The Navy Operational Global Atmospheric Prediction System (NOGAPS) consists of four separate components—data quality control, data analysis, initialization, and the forecast model. NOGAPS operates in a 6-hr update data assimilation cycle, with the 6-hr model forecast serving as the background field for the data analysis, which in turn provides the fields for the initialization of the forecast model. The forecast model is an 18 σ-level, 79-wave triangular truncation, global spectral model with a nonlinear normal-mode initialization (Hogan and Rosmond, 1991). The data analysis uses the multivariate optimum interpolation (MVOI) technique described by Goerss and Phoebus (1991) to analyze geopotential height and the u- and v-wind component increments on standard pressure surfaces. The analysis fields are produced for 16 standard pressure levels (1000–10 mb, plus 925 mb) on the 1.5° resolution Gaussian grid of the spectral forecast model.

Since the MVOI is a three-dimensional incremental analysis, observations made at various heights can influence the analysis results at 1000 mb. However, high quality upper-air profile measurements over the oceans are limited to a few island radiosonde stations and an occasional balloon launch from a ship. While these observations provide some information about the structure of the lower atmosphere, their numbers are too few to have much impact. The conventional upper-air observations are supplemented by temperature soundings from the polar-orbiting satellites. Although these soundings are plentiful, accuracy is a problem. Other data sources include single-level wind reports from aircraft and cloud-tracked wind observations estimated from the geostationary satellites. The low-level satellite winds are normally concentrated at the 925–850 mb level, while the upper-level satellite winds and the aircraft data are predominently at the 250–200 mb level. Over water, conventional sources of surface data include observations from ships, moored and drifting buoys, and Coastal-Marine Automated Network stations. These marine surface reports are concentrated primarily in the northern hemisphere, along major shipping routes.

The relative sparseness of data over the oceans certainly hinders efforts to produce accurate analyses and forecasts of meteorological conditions in these areas. The effect is most noticeable in the southern hemisphere, of course, where the ratio of sea to land is greater and the lack of data is even more pronounced. The only practical solution to this problem is to develop and deploy high-quality remote sensors. A step towards that goal was achieved on June 19, 1987, when the first Special Sensor Microwave/Imager (SSM/I) was launched by the Defense Meteorological Satellite Program (DMSP). The SSM/I is a passive microwave radiometer that provides high-resolution measurements of a variety of environmental parameters—among them, rain rate, precipitable water, marine wind speed, sea ice location and concentration, soil moisture, and land surface temperature.

Of particular interest for meteorological data assimilation are the SSM/I wind speed data. While the resolution, quality, and coverage of the SSM/I data are excellent, their usefulness is somewhat limited by the lack of directional information. Nonetheless, early tests indicated that there would be a small positive impact if the data were included in the analysis (Goerss, 1989a). Given that this positive impact would be in an area of high Navy interest, namely the marine boundary layer, the operational assimilation of SSM/I wind speed data into NOGAPS was initiated on September 12, 1990. The positive impact of these observations on the operational system is described in Phoebus and Goerss (1991). The initial implementation of the SSM/I wind speed data used a preliminary 1000 mb analysis to assign wind direction. Since that time, we have investigated alternative methods of assigning wind direction, and those results are reported here.

2. SSM/I DATA PROCESSING

2.1 Preliminary Quality Control

The SSM/I data are processed and stored by the Navy in near real-time at Fleet Numerical Oceanography Center (FNOC). FNOC uses the algorithm of Goodberlet, *et al.* (1990) to estimate the ocean surface (19.5 m) wind speeds from the SSM/I measured brightness temperatures. These speeds have a range of 3–25 m s^{-1}, and meet the specified accuracy of ±2 m s^{-1} in rain-free conditions. Since heavy concentrations of water vapor and rain effectively mask microwave emission from the ocean surface at the SSM/I frequencies, wind speed retrievals under these conditions are more likely in error. Currently, the NOGAPS data preprocessor screens the SSM/I data so that only rain-free observations are used in the MVOI. Furthermore, any wind speed reported outside the range of the SSM/I instrument is ignored.

The wind speed data are also subjected to quality control procedures that compare the observed wind speeds to a *preliminary* analysis field. Whether or not an observation is rejected during this comparison depends upon both the observed wind speed and the wind speed from the preliminary analysis valid at the observation location. The strictest crite-

ria are applied and the most data are rejected (~ 5%) when the analyzed wind speed is very light and the SSM/I wind speed is substantially stronger. Since the preliminary analysis will also be used to assign wind directions to the SSM/I observations, this decision reflects the fact that it would be inappropriate to assign a wind direction from a light and variable condition to a stronger wind speed. The other categories exhibit more tolerance for differences between the preliminary analysis and the SSM/I data and, as a result, reject fewer observations.

The preliminary analysis is run using the same software and the same background fields as the NOGAPS analysis, but is executed at only 2 hours past the synoptic time (compared to +9.5 hours for the update cycle), so it has a shorter data window. Analyzed fields are produced only at the four pressure levels nearest the surface. The preliminary analysis uses almost all of the available data, except for aircraft wind reports, satellite temperature soundings, and, of course, the SSM/I wind speed data.

2.2 Computation of Superobs

A typical 6-hour coverage by the SSM/I produces in excess of 200,000 observations at approximately 25 km resolution, a resolution much higher than the effective resolution of NOGAPS. Thus, to reduce the number of data points without losing information on scales relevant to NOGAPS, the SSM/I data are combined into *superobs*, which are essentially local averages of groups of observations.

Before the superobs are computed, the wind speeds from the preliminary analysis are interpolated to the location of each individual observation, and the interpolated values are subtracted from the observed wind speeds to form SSM/I wind speed increments. Next, the globe is divided into 200 km boxes and, given sufficient numbers of observations, the SSM/I wind speed *increments* within each box are averaged. The increments rather than the original values are used because, in general, the increment field is more horizontally homogeneous than the raw data. Once the superob increments are computed, the superob wind speeds are obtained by adding the increment in each box to the preliminary analysis wind speed interpolated to the center of the box.

3. ASSIGNMENT OF WIND DIRECTION

The analysis variables are geopotential height and the u- and v-wind components—variables that have well-known dynamical relationships. The design of the MVOI analysis is such that it cannot utilize scalar wind speed information directly. So, once the SSM/I superob wind speeds have been computed, each superob wind speed must be assigned a wind direction. There have been several techniques proposed for independently determining appropriate directions for the SSM/I wind speeds. Atlas *et al.* (1991) combine conventional wind data and SSM/I winds with background analyzed surface wind fields from the European Centre for Medium Range Weather Forecasts, using variational techniques to constrain the degree to which the SSM/I data can modify the background. Yu (1987) bases his technique on Ekman boundary layer dynamics, using the National Meteorological Center's surface pressure analysis and the SSM/I wind speed to compute the surface drag coefficient, which then allows the computation of the vector wind at some height z^* within the boundary layer (typically 10 m).

In our case, we use the power of a global data assimilation system to produce a preliminary analysis using the most recent data, independent of the SSM/I. Originally, the 1000 mb wind field from the preliminary analysis was used to assign SSM/I wind direction. However, the NOGAPS forecast model produces a 10 m wind field from the lowest model σ-level (~ 40 m), primarily to provide forcing data for the FNOC oceanographic models. The 10 m winds are stability dependent and consistent with the model's boundary layer physics. Thus, the assigned SSM/I wind directions are now taken from the analyzed 10 m wind field, which is horizontally interpolated to the location of each superob. Once the directions have been assigned, the SSM/I superobs are processed like any other surface wind observation and are assumed to have the same observational error as wind observations from ships.

An improved technique for assigning wind direction to the SSM/I wind speeds is under development. The current operational technique just described is heavily dependent upon the MVOI analysis background fields in areas sparsely covered by marine surface data. The accuracy of these background fields, which are 6-hour forecasts from the global spectral model, is dependent upon the performance of the forecast model. In the northern mid-latitudes, where weather systems typically move from west to east, the accuracy of the background fields over ocean areas is greatest just to the east of the data-rich continental areas and decreases from west to east. The largest errors in the background fields are associated with incorrect forecasts of the position and/or intensity of extra-tropical cyclones. The error that is most critical to the assignment of SSM/I wind direction is that associated with an incorrect position forecast. In such situations, the background fields normally depict quite well the structure of the cyclone and its associated fronts but show an offset in their positions. As a result, in the absence of other data, the wind directions assigned to the SSM/I wind speed observations by the current technique would reflect the erroneous offset. The goal of our research is to utilize the SSM/I wind speed observations to determine and correct for such offsets before the wind direction is assigned.

Prior to computing cross-spectral quantities like the coherency or phase spectra, it is common practice in time series analysis to align the two time series (Jenkins and Watts, 1968). This is done by lagging one time series with respect to the other and computing the values of the cross-covariance function for the different lags. The lag at which the maximum value of the cross-covariance function is found is used to align the time series. This technique was utilized by Duchon and Goerss (1976) in their time series analysis of aircraft data from intercomparison flights performed during the National Hail Research Experiment. These flights typically consisted of three aircraft flying in formation with one in the lead. The data from these flights consisted of samples 1 second apart. Before performing cross-spectrum analysis upon the time series from the aircraft, the data sets from the trailing aircraft were aligned to that from the lead aircraft by measuring the time displacement from zero of the peak in the cross-covariance functions. The location of this peak could be easily defined and the resulting time displacement was attributed to the persistent longitudinal separation between the aircraft and to asynchronization of the aircraft clocks.

We propose to use an analogous technique in areas sparsely covered by marine surface observations to spatially align the SSM/I wind speed observations with the preliminary analysis wind fields prior to the assignment of wind direction. For an area of appropriate size, for which there is sufficient coverage by SSM/I wind speed observations, we can compute the correlation between the wind speed observa-

tions and the wind speeds from the preliminary 10 m analysis at the location of the observations. We then spatially shift the preliminary analysis with respect to the SSM/I observations and recompute the correlations for spatial lags in the east-west and north-south directions to determine the lag for which this correlation is a maximum. The wind directions from the shifted analysis are then assigned to the SSM/I wind speed observations, but the observations themselves are not actually displaced.

We illustrate this technique for an area located between 30°S and 60°S, 90°W and 120°W. In Fig. 1 the isotachs from the unshifted preliminary 10 m analysis are plotted along with the SSM/I wind speed suberobs. In the northern half of this domain, there is a northwest-to-southeast axis of minimum wind speeds in the background field that is located to the southwest of a similar axis in the wind speed observations. Similarly, the center of maximum winds in the south-central part of the domain is located southwest of the corresponding maximum wind speed superobs. Table 1 provides the correlations computed by systematically shifting the preliminary analysis relative to the SSM/I wind observations, using 1.5° increments in the east-west direction and 1.0° increments in the north-south direction. The maximum correlation is found by shifting the preliminary analysis 1.0° to the north and 4.5° to the east.

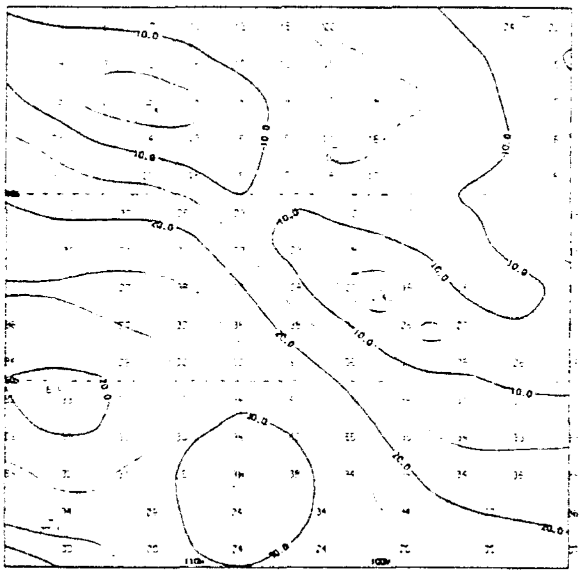

Fig. 1. SSM/I wind speed superobs (kts) available at 12Z, August 22, 1991, compared to the preliminary analysis of 10 m wind speeds countoured every 5 kts.

TABLE 1. Cross-correlations

Between SSM/I and Offset Background Wind Speeds
Computed over Area from 60°-30°S, 120°-90°W

x-offset	-6.0°	-4.5°	-3.0°	-1.5°	0.0°	1.5°	3.0°	4.5°	6.0°
y-offset									
4.0°	62	.68	.72	.75	.77	.76	.73	.67	.60
3.0°	.56	.62	.69	.74	.78	80	.78	.74	.68
2.0°	.48	.55	.63	.70	.76	.80	.81	.79	.75
1.0°	39	.46	.55	.64	.72	.78	.82	.82	.80
0.0°	.30	.37	.45	.55	.64	.72	.78	.82	.82
-1.0°	.22	.27	.35	.44	.54	.64	.72	.78	.82
-2.0°	.14	.18	.25	.34	.43	.54	.63	.72	.78
-3.0°	.07	10	.15	.23	32	.43	.53	63	72
-4.0°	01	.02	.05	12	.21	31	42	53	63

Fig. 2 shows the analyzed 1000 mb wind field computed using the current technique, with direction assigned from the preliminary 10 m wind analysis. In comparison, Fig. 3 shows the comparable field, but in this case, the SSM/I wind directions were assigned by shifting the background field relative to the data. As you can see from the streamlines, this results in a slight eastward shift in the centers of circulation, most noticeable in the northwesterly section of the grid.

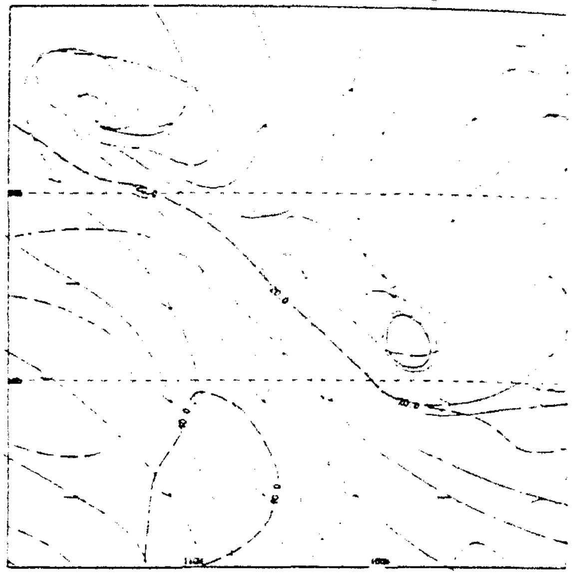

Fig. 2. Streamlines and isotachs (contoured every 10 kts) at 1000 mb, from analyzed fields produced for 12Z, August 22, 1991 using SSM/I wind data with directions assigned from the preliminary 10 m analysis field.

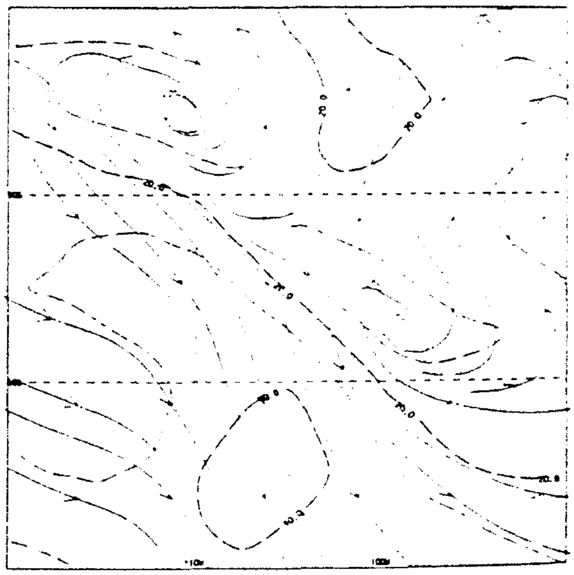

Fig. 3. Same as Fig. 2, but with wind direction assigned to the SSM/I data from the shifted 10 m analysis field most highly correlated with the SSM/I data over the area shown.

We plan to test the application of this technique first in the southern hemisphere mid-latitudes. The marine surface data coverage in the northern hemisphere mid-latitudes is fairly extensive and is supplemented by the generation of synthetic surface observations in the vicinity of extra-tropical

cyclones (Goerss, 1989b). While the tropics are not as well covered by marine surface data, significant tropical circulations are accurately depicted in NOGAPS through the inclusion of synthetic soundings that are generated using information contained in the warning messages issued by the Joint Typhoon Warning Center, Guam and the National Hurricane Center, Miami (Goerss *et al.*, 1991). Thus, the largest errors are undoubtedly associated with extra-tropical highs and lows in the Southern Hemisphere. However, the technique may prove useful in other areas, as well.

While this experiment demonstrates the feasability of the technique, for operational application we must determine ways to automatically identify those areas where a phase error in the background is likely. In that regard, this work is closely related to another of our research interests, that is, identifying areas where the background errors are larger than those assumed by the MVOI analysis, so that the specified background error can be modified in real-time over limited areas. The goal of this effort is to identify quantities that serve as useful predictors for locating such occurrences. Once these areas are identified, they would also be likely candidates where the alternative method of assigning SSM/I wind direction would prove beneficial.

4. CONCLUSIONS

SSM/I wind speed data provide an abundant source of information for improving low-level marine analyses and forecasts, an area of key importance for support of naval operations and the ocean modeling community. All indications are that this data source is of high quality and has had a positive impact on the performance of the global data assimilation system. To utilize the SSM/I data, the primary decision that must be made is how to assign a wind direction to each observation. In NOGAPS, we currently use the 10 m wind fields computed from a preliminary low-level analysis of conventional data and satellite cloud-tracked winds.

However, in spite of the relatively close agreement between the SSM/I data and the preliminary analysis wind speeds, visual comparison of the fields indicate that in some cases there are phase differences. A preliminary study computing cross-correlations of the SSM/I and preliminary analysis wind speeds substantiates this phase error. When the SSM/I data locations are offset in another direction, the cross-correlation with the background is often increased, while the number of SSM/I observations rejected by the analysis quality control procedures is reduced. Thus, future efforts will concentrate on improved ways to assign wind direction to the SSM/I wind speeds and how to implement such procedures operationally. These methods should also prove useful for resolving any wind direction ambiguity problems associated with the ERS-1 scatterometer winds when they become available.

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